91602
new 82-10

ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research If
Reproduced in Whole or In Part

To: Dr. D. Mills
Director of Research

TRIP REPORT ON CONFERENCE ON LASERS AND ELECTRO-OPTICS 1987, BALTIMORE, MARYLAND, APRIL 27 - MAY 1, 1987

H.D. Morrison

A joint meeting of the Conference on Lasers and Electro-Optics and the International Quantum Electronics Conference was held this year in Baltimore. A paper on zirconium isotope separation based on collaborative work with the National Research Council of Canada was presented and served to establish new contacts in this field. Topics of interest at this meeting included developments in optical materials, laser processing, diode lasers, fiber-optic sensors, and fundamental physics. Technical digests summarizing all the proceedings of both conferences are available on request. The trade exhibit that accompanied the conferences was useful for learning about new laser-related products and maintaining personal contacts with company representatives.

INTRODUCTION

The annual meeting of the Conference on Lasers and Electro-Optics (CLEO) was held in conjunction with the Fifteenth International Quantum Electronics Conference (IQEC) in Baltimore, Maryland. Both conferences are sponsored by the optical Society of the IEEE. In addition, the Quantum Electronics Conference is also sponsored by the American Physical Society. The sources of sponsorship reflect the division of topics between the two conferences. CLEO covers research and development in all fields of lasers and electro-optics with an emphasis on engineering and applications while IQEC addresses all aspects of quantum electronics with an emphasis on fundamental physics. The attendance at the two conferences was down slightly from last year but the interest was heightened by a more exciting program of over 900 papers. The accompanying technical exhibit by almost 300 manufacturers, distributors and publishers of laser-related products was excellent as usual.

job	file	date	report no.
16-529	819.39 X819.35	July 3, 1987	87-159-K

The tone of the week was set by the joint plenary session on the first day. Four lectures were delivered on topics at the frontiers of laser-related developments and applications. The first speaker was Robert Byer of Stanford University who discussed "The Renaissance in Solid-State Lasers". Virtually neglected for almost a decade, the solid-state laser has recently seen significant advances in efficiency, average power, linewidth control, wavelength range and tunability. Improved pumping geometries and crystal growth as well as new crystal materials have led this trend. Dramatic increases in the power from diode lasers has led to diode pumped crystal lasers, with output at visible wavelengths in the green, blue and red obtained by frequency doubling. This opens the possibility to wholly solid-state devices for colour image projection displays. Byer concluded by predicting that the cost per watt of diode-laser power is decreasing so fast that by 1989 it will be cheaper to produce 1 W from a Nd:YAG laser by pumping with a diode laser than with any other pump source. By 1991 that power will be 10 W and by 1993 it will be 100 W. These developments could revolutionize lasers for material processing.

Steve Chu of AT&T Bell laboratories, presented the second talk of the plenary session on the fundamental physics of "Optical Molasses, Laser Traps, and Ultracold Atoms". He reviewed the dramatic progress in the demonstration of the mechanical effects of light on atoms that has led to the confinement of more than 10^6 atoms for longer than 10 s with densities as high as 10^{12} atoms/cm^3. The optical molasses is the viscous fluid of neutral atoms cooled by six crossed laser beams. Within the molasses, a single focused laser beam forms a trap for condensing atoms to temperatures less than 1 mK. The highlight of the talk was a video presentation recorded in his laboratory demonstrating the visible fluorescence of a diffuse cloud of optical molasses lasting for several seconds at a time. Within the cloud, a small bright spot signaled the much higher density of atoms in an optical trap. The trap full of atoms could be moved at will simply by moving the laser focal point within the optical molasses, thus demonstrating the effect of optical tweezers. These developments in laser cooling and trapping pave the way for many paths of investigation in the fundamental physics of ultracold atoms and gases.

The third and fourth talks of the plenary session dealt with laser applications in materials science and a review of the American Physical Society Report on directed energy weapons, respectively. Richard Osgood of Columbia University reviewed the increasing use of lasers for basic materials science especially in the semiconductor industry. These lasers are employed for etching trenches in silicon, depositing electrical connections, and a variety of other tasks. Kumar Patel of AT&T Bell Laboratories, summarized the APS Report that was funded by non-governmental agencies and investigated the scientific feasibility of directed energy weapons/1/. The overall conclusion was that many scientific breakthroughs are required to achieve the several orders of magnitude improvement required to produce devices envisioned by the "Star Wars" program in the United States. Gradual improvements in engineering that follow in the natural course of developing any product or device will not be sufficient. Patel presented convincing arguments that the report conclusions were valid, based in part on the access to US government classified material that was made available to the authors of the report.

After the joint plenary session the two conferences proceeded with eight parallel sessions of invited and contributed papers. Many of the sessions were of interest but they could not all be attended because of conflicting schedules. Summaries and discussion of the sessions that I attended are grouped together below under five topic headings.

The five headings are Optical Materials, Laser Processing, Diode Lasers, Fiber-Optic Sensors and Fundamental Physics. First, though, is a summary of the contributed paper I presented on laser isotope separation of zirconium. Technical digests containing summaries of all papers at both conferences were published and are available for loan from this author.

Paper on Zirconium Isotope Separation

The paper, entitled "Laser Separation of Zirconium Isotopes", was contributed by the author of this report and Drs. Peter Hackett, David Rayner and Orson Bourne of the National Research Council of Canada.

This presentation was an extension of the work that has already been described in Research Report No 87-60-K. The motivation for separating zirconium isotopes is to enhance the lifetime and safety of in-core CANDU reactor components, especially pressure tubes, by virtue of making them thicker. Zirconium components such as these, can be made 50% thicker without increasing their cross-section for neutron absorption if the zirconium-91 isotope is depleted from its natural abundance of 11.2% down to 6.5%. The method proposed to separate this isotope is atomic vapour laser isotope separation (AVLIS) whereby zirconium atoms are selectively ionized by absorbing laser light and then the ions are collected separately from the neutral atoms. This paper addressed the central problem of selective ionization by laser, known as photoionization. Isotope selective photoionization is usually based on the slight shifts in frequency in the absorption spectrum of atoms. In zirconium the isotope shifts are too small to be exploited and so zirconium AVLIS must rely on the hyperfine splitting and shifts of the zirconium-91 isotope. Experiments were directed towards measuring these hyperfine shifts and exploring possible photoionization schemes. One experiment examined the isotope selectivity which was found to be at least 10 in the frequency range of interest. A simple economic model was used to compare the laser costs of several photoionization schemes based on a selectivity of 10. The least expensive option could provide denatured zirconium (6.5% ^{91}Zr) at a cost for the laser work of $400/kg of product if several simple assumptions hold true. (A more detailed analysis will be issued in a separate report.) Costs for producing the atomic beam and separating the ions from the atoms are difficult to estimate but would probably equal the laser cost. In conclusion, AVLIS is potentially a practical method for zirconium separation. More work on all aspects is required to refine the cost predictions and develop the appropriate technology based on the uranium AVLIS program at Lawrence Livermore Laboratory.

As far as I could tell, this was the only paper at the conference that was directly related to laser isotope separation. This points out a substantial decline of interest in this area by the laser community since last year. A major influence has probably been the successful progress towards commercial operation of the uranium AVLIS program at Livermore. Since that problem is "solved" there is less incentive and less money to pursue similar lines of research. Whatever the reason for the absence of other reports on separation, the zirconium paper did generate some interest since four people did approach me afterwards to discuss my work. The first was Dr. Jean-Marie Gagnè of Ecole Polytechnique in Montreal. He had been performing hyperfine spectroscopy measurements on uranium and is now directing his attention to the hyperfine spectroscopy of zirconium. His measurements and mine are complementary and overlap in places, thus it may be worthwhile to visit his laboratory to provide more time for discussion and information exchange. Later I was approached by a scientist (unfortunately I did not discover his name) from Belgium connected with uranium enrichment by centrifuge (URENCO). He expressed his concerns about some of the technical problems inherent in AVLIS for zirconium. I was able to deflect some of his concerns by mentioning that Livermore had successfully developed uranium AVLIS and that zirconium and uranium had similar properties. One obvious concern is the much higher melting point for zirconium than uranium to which he suggested

that we do as Livermore has done and employ a zirconium alloy with a lower melting point as the atomic beam source. However, my feeling is that, that solution merely adds another problem - that of separating the zirconium from the alloy after the isotope separation process.

A third contact was Dr. Victor Vetskov of the Institute of Stable Isotopes in the USSR. He simply wanted to discuss my paper so that he could grasp some of the ideas he had missed during the presentation. It was not clear whether he was connected with any effort on zirconium separation.

The fourth new contact was Dr. Francois Viala of the Commissariat a l'Energie Atomique in France. There they have been working on uranium AVLIS for several years but the research funding for that is now decreasing while interest in isotope separation of zirconium and gadolinium is increasing. The object in gadolinium separation is to enrich the isotope that has a high cross-section for neutron absorption and thus has application to the rapid shutdown of nuclear reactors. Dr. Viala, works only with the laser aspects of separation but he agreed to send some unclassified material he had on all aspects of their separation program.

Optical Materials

Five sessions at CLEO were related to optical materials and discussed laser materials, frequency conversion and optical damage. In the area of frequency conversion three crystal types held a special interest, two for the infrared wavelength region and one for visible wavelength. One of the infrared crystals was $AgGaSe_2$ which has been under development for commercial sale by Cleveland Crystals since 1984 at least. This crystal is very promising for frequency doubling CO_2 lasers but unfortunately is not commercially available yet: Cleveland Crystals is not making any promises either according to its sales manager at the trade exhibit. The reason given is the difficulty in growing high quality crystals on a reliable basis. A joint paper by Cleveland Crystals, NASA Langley Research Centre and Los Alamos National Laboratory presented results on using $AgGaSe_2$ as a parametric amplifier. This application further illustrates the potential versatility and utility of this crystal if it were available.

Another paper discussed recent progress in the development of thallium arsenic selenide (TAS), a rival candidate to $AgGaSe_2$ for frequency doubling CO_2 lasers. A second harmonic conversion efficiency of 28% at an energy fluence of 1 J/cm^2 was reported by the Naval Research Laboratory. Unfortunately, TAS is also difficult to grow and at the moment is only being manufactured at the Westinghouse Research Laboratory. Thus it is unlikely that any TAS will be commercially available within the next few years.

In the last couple of years a marvelous new doubling crystal for the visible, β - $BaBO_4$, has been developed in China at the Fujian Institute of Research on the Structure of Matter. Dr. Chuangtian Chen, presenting an invited paper, reviewed progress in the development of β - $BaBO_4$. Some highlights are listed here. Inclusion-free material can now be grown and it has a damage threshold of 20 Gw/cm^2 in a 10 ns pulse. It has a useful transmission range for nonlinear processes from 194 nm in the ultraviolet to 2.64 μm in the infrared. In a detailed comparison with KDP, a well-developed nonlinear crystal, β - $BaBO_4$ provided better performance for many applications. Meanwhile, at the trade exhibit, the sole distributor for these crystals was proudly announcing that β - $BaBO_4$ was in stock.

Laser Processing

One growing application for lasers is as a heat source in the synthesis of materials. An invited paper by Dr. John Haggerty of the Massachusetts Institute of Technology, discussed the synthesis of ceramic powders and thin films from gases heated by a CO_2 laser. Most of their work has been with silicon materials employing SiH_4 as the feed gas. They have produced a few grams/hour of high quality SiC powder by crossing the gas stream with a laser power of 1 kW/cm^2 in a cold wall vessel. The powder particles were spherical, less than 1 micron in diameter, highly uniform in the distribution of diameters, and not agglomerated. The purity and quality of these particles was also demonstrated by sintering the particles into a solid material that was free of defects. Conventional particle production methods cannot obtain such high quality. However, the laser method is costly and can only be competitive if there is a high mass flow and a minimum time at high temperature. In the field of thin films, Haggerty described the laser-induced chemical vapour deposition of boron-doped films for semiconductor materials. Much less laser power was required for their work than for particle production: the absorbed power per unit length was typically 0.5 - 1.5 W/cm. Haggerty also mentioned work on amorphous SiH films, a material of interest for solar cells, but that research is not complete.

Another paper in the area of laser processing was presented by Dr. T. Yamada of Toshiba. He described the construction details and performance of a 1 kW continuous power Nd:YAG laser. The laser system employs three laser rods in one resonator, with each rod pumped by Kr arc lamps. The total input power (optical of 37 kW yields a maximum laser power of 1.08 kW with a beam divergence of 35 mrad. The laser power is conveyed to the work zone by step index quartz fiber (NA = 0.2) : a fiber of 1.2 mm diameter delivered 900 W and one of 0.8 mm diameter delivered 700 W. Three applications were reviewed: internally brazing a 20 mm ID pipe, welding stainless steel, and hardening of high carbon steel. For welding, the laser intensity was modulated 40% at 50 Hz to achieve greater penetration. The hardening operation was successful. It produced micro-structural changes to a depth of 0.7 mm in a band 12 mm wide at a linear rate of 0.24 m/min without an absorption coating.

In the trade exhibit, Lumonics demonstrated one of its newest products: a laser machining system incorporating an excimer laser. As this laser type emits high power ultra-violet light, it is best suited to applications that involve removing small amounts of material, especially organic materials such as polymer films. Thus excimer lasers have become very useful in the semiconductor industry. The presence of the Lumonics product and the great interest it generated at the exhibit are indications of the increasing importance of excimer lasers as a tool for material processing.

Diode Lasers

As discussed by Dr. Byer in the plenary session, solid-state lasers are once again a hot topic in the laser community. Semiconductor diode lasers are an integral part of this renaissance as was demonstrated by the scheduling of eleven sessions at CLEO devoted to these lasers. Several other sessions on solid-state lasers and optical communications discussed other research and applications involving diode lasers. The most exciting developments lie in the area of high power diode lasers and arrays. Linear arrays are commercially available now that produce 20 W/cm at 20% efficiency. One research laboratory reported a peak power of 134 W in a device 1 cm wide at 49% efficiency. This power is produced in a 150 μs long pulse, which is a pulse energy of 20 mJ, at a repetition rate of 50 Hz. Similar devices are being developed as 2-dimensional arrays producing 2 kW/cm^2 in the laboratory now. The far-field pattern of these laser arrays is not uniform, and so their main application is for pumping other lasers at close range. Eventually though, these devices could replace Nd:YAG lasers in material processing applications.

One paper was a "Report on the Fourth International Workshop on Semiconductor Laser Device Physics", which had taken place the day before CLEO started. One of the four sessions at the workshop was devoted to high power devices. Another session discussed single frequency and tunable lasers. Single frequency refers to achieving a narrow linewidth which could be applied to coherent communications. However, a discussion group at the workshop resolved that a narrow linewidth is not necessary for communication devices in general. The group also resolved that the best method for obtaining tunable single frequency operation is with a 3-section device: one section for gain, one for phase tuning and one for frequency tuning. Fujitsu has developed such a device which provides tuning over 25A by increasing the device current from 0 to 50 mA. Another group at the workshop devised a list of types of optical-electronic integrated circuits. Ranked by market share, the most common device type is optical interconnection, followed by lasers and electronic switches in second place. Fifth on the list is high power coherent lasers, and twelth and last is laser ring gyroscopes. This partial list gives some idea of the scope of semiconductor laser devices. According to a recent economic report, world-wide commercial sales of diode lasers was US $121 million in 1986 out of total laser sales of $502 million/2/.

Fiber-Optic Sensors

As there is another annual conference run by the Optical Society of America that deals exclusively with fiber-optic sensors, it was not surprising that there was only one session at CLEO for this topic. The session began with a review paper by Dr. Thomas Giallorenzi of the Naval Research Laboratory, who explored the many types of sensor available today for measuring over fifty different variables, such as pressure and temperature. The main message of the review was that in ten years, the sensor technology has matured so that research has shifted from concept validation to packaging issues related to reliability, cost-effectiveness and environmental factors. In many cases, fiber-optic sensors are still much more expensive than conventional sensors but they can operate in harsher environments and so the market is growing.

One paper of special interest was presented by Dr. K. Gratton of the School of Electrical Engineering and Applied Physics in London, England, who discussed a sensor for measuring temperature over the range of 300 - 1100 K. The device senses temperature with a rod a few cm long made of Nd:YAG at the end of a fiber bundle. The fiber transmits light from a light-emitting diode to excite the rod and generate fluorescence. The decay time of the fluorescence, monitored via the fiber on a diode detector, is a measure of the temperature of the rod independent of the absolute fluorescence intensity. A special feature of this device is its microprocessor control and timer to sample the temperature at rates up to 1 kHz and average up to 32,000 samples. A single measurement with this device provides a temperature resolution of less than 5 K. This temperature sensor bridges the gap in temperature measurement between a device by Luxtron that senses up to 400 K, and a device from Accufibre that operates above 800 K.

The trade exhibit also afforded the opportunity to speak to representatives of Infrared Industries about work I had done on a fiber temperature sensor with one of their detectors. The sensor is a distributed device that operates by employing the entire length of a fiber as a blackbody emitter/3/. This type of device could be useful for measuring the hot spot in a transformer. There is a revival of interest in the blackbody sensor after it was found unsuitable for routine installation in generators to monitor stator temperatures. The discussion at the exhibit yielded several ideas for improving and testing sensor performance with custom detectors manufactured by Infrared Industries.

Fundamental Physics

Several of the more interesting topics at IQEC were included in several sessions on Laser Spectroscopy and Physics that examined issues of fundamental physics. One paper from the University of Maryland presented a new version of the Einstein-Podolsky-Rosen (EPR) experiment to compare the predictions of quantum mechanics to those of Bell's Inequality. This type of experiment is at the core of an ongoing fundamental, philosophical debate in physics on whether quantum mechanics provides a complete description of physical reality or some other theory is required. The issue is complex and may not be resolved for many years to come but the results of this new test are consistent with quantum mechanics and violate Bell's Inequality.

One entire session was devoted to papers on the new quantum adiabatic phase, known as Berry's phase, that was discovered four years ago and has found application in many fields/4/. The first paper was an invited presentation by Dr. M. Berry, the discoverer of the new phase. In an entertaining talk, Dr. Berry described the quantum adiabatic phase as a geometrical phase factor that is path dependent and appears in cycled systems as a failure of some variables to return to their original values when others do. As a classical analogue, he described a weather-vane, rotating at constant speed ω that is placed at the North Pole. If the rotating vane is transported down a line of longitude to the Equator, east along the Equator, and finally back up a line of longitude to the North Pole, then the phase of the vane's rotation with respect to its starting position contains two terms. The first phase term is simply ωT, where T is the time taken for the trip, which is a dynamical phase that answers the questions, "How long have I been gone?". This first term does not account for all of the phase. The second term in the phase arises from the fact that the path of the weather-vane occurred on a spherical surface and thus it answers the question, "Where did I go?". This geometric part of the phase depends only on the path travelled by the weather-vane. The geometric phase appears in all systems that contain spin which includes atoms, molecules, liquid crystals and light. Apparently, hints of this phase have appeared in the literature of several fields for many years but it was not recognized for what it was.

In the second talk, a demonstration of Berry's phase was provided by passing polarized light through a fiber-optic coiled in a helix/4/. The pitch of the helix affected the plane of polarization of the light that emerged from the fiber. By merely extending or compressing the helix like a large spring, the light polarization was seen to rotate. The effect was shown to be purely geometrical and independent of wavelength. As the recognition of this phase becomes more widespread it is sure to appear in many other applications.

One exciting new development that has only been demonstrated within the last year, is the experimental observation of quantum jumps in single atoms/5/6/. In 1913, Bohr postulated that atoms undergo instantaneous transitions, now called quantum jumps, by the emission or absorption of light quanta or photons. At the time this was considered to be an artifact of Bohr's atomic theory and impossible to verify since atoms, if they existed, only appeared in large groups. Recently, lasers and ion traps have been applied to cooling and trapping single ions. Once trapped, the ion can be probed with another laser to produce fluorescence. The fluorescence arises from the atom cycling between two states and thus scattering the probe light. If there is a longer lived state available from either of these two states then the atom occasionally stays in this third state and the fluorescence stops. An invited paper by Dr. J. Bergquist of the National Bureau of Standards, showed a movie taken in their labs of the fluorescence from an ion trap, turning on and off abruptly. The effect is impressive and convinced me that quantum jumps exist.

SUMMARY

The 1987 joint conference of CLEO and IQEC in Baltimore was well attended by an international collection of scientists from all fields of lasers and electro-optics. The program of papers was more interesting than last year, highlighted as it was by several exciting developments of which some are briefly described in this report. At the opening of the conferences, the plenary session was especially interesting and set the tone for the week-long program. Only one paper directly discussing isotope separation was presented, and that from a collaboration of Ontario Hydro Research Division and the National Research Council of Canada on separating zirconium isotopes. This paper served to establish new contacts in other research establishments. Other papers at the conferences are discussed in this report under the major headings of optical materials, laser processing, diode lasers, fiber-optic sensors, and fundamental physics. Some of the topics have a direct connection to current activities at each Division, while the rest help to maintain an awareness of developments in lasers and electro-optics overall. The trade exhibit accompanying the conferences provided a good opportunity to meet with representatives of manufacturers and distributors and to learn about their new products. On the whole, it was informative and worthwhile to attend this conference.

Approved:

M Edgar

for A.F. Baljet
Manager
Electrical Research Department

HDM:CB

Submitted:

Hugh Morrison

H.D. Morrison
Engineering Physicist
Science Section
Electrical Research Department

REFERENCES

1. Physics Today, May 1987, pp S1-S16.

2. Laser Focus, January 1987, pp 52-53.

3. Morrison, H.D. "Blackbody Fiber-Optic Temperature Sensor." Research Report No E85-40-H.

4. Robinson, A.L. "An Optical Measurement of Berry's Phase." Science 234, 424-426 (1986).

5. Bergquist, J.C. et al. "Observation of Quantum Jumps in a Single Atom." Phys. Rev. Lett. 57, 1699-1702 (1986).

6. Souter, Th. et al. "Observation of Quantum Jumps." Phys. Rev. Lett. 57, 1696-1698 (1986).

DISTRIBUTION

Dr. D. Mills	Director of Research
Mr. A.F. Baljet	Research
Dr. N. Anyas-Weiss	Research
Dr. K.B. Woodall	Research
Dr. L. Mannik	Research
Dr. J.R. Robins	Research
Dr. F.E. Bartoszek	Research
Dr. K.E. Donnelly	Research
Dr. H.D. Morrison (2)	Research

Public Reference Centre
Editorial Section (2)
Office Copies (2)
Extra Copies (3)